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Evaluation of Heel-Effect Impact on AEC Cell Balance Quality Control

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PURPOSE

The x-ray tube heel effect produces spatial variations in beam intensity that can influence automatic exposure control (AEC) termination at different AEC cell locations. This study evaluates the influence of the heel effect on AEC cell balance testing methodologies in digital radiography.

INTRODUCTION

Current radiographic AEC quality control guidance, including AAPM Task Group 150, does not explicitly address beam nonuniformity caused by the x-ray tube heel effect during AEC cell balance testing[1].

Because AEC cells are positioned at different locations within the radiation field, spatial differences in beam intensity may affect AEC termination and create apparent differences in cell response. These differences may be incorrectly interpreted as true AEC cell imbalance.

This study presents a measurement-based method for quantifying the contribution of the heel effect and other off-axis effects to AEC cell balance measurements and assesses the significance of these effects in performance testing. This work provides evidence-based guidance to help medical physicists distinguish true AEC cell imbalance from differences caused by beam nonuniformity and may inform future refinement of radiographic AEC quality control recommendations.

REFERENCE

1. AAPM Task Group 150. Quality Control in Diagnostic Radiology. AAPM Report No. 150. American Association of Physicists in Medicine; 2015.

DISCLAIMER

The concept for this work originated from AAPM Task Group 421. However, this presentation reflects the independent work and perspectives of the authors and does not represent a position or endorsement by the AAPM.

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METHODS AND MATERIALS

AEC cell balance was evaluated on seven table and nine wall Buckys from five radiographic system vendors. Measurements were performed by three medical physicists at two institutions.

DATA COLLECTION

Flat-field exposures were acquired using an RQA-5 beam with one AEC cell active at a time. For each exposure, the following metrics were recorded:

- AEC-terminated mAs
- Exposure index (EI)
- Mean pixel value (MPV) within the active-cell region of the *for-processing* image

Air kerma was measured at each AEC cell location using a solid-state dosimeter on the Bucky and a manually selected technique. Measurements were scaled to account for differences between the AEC-terminated and manually selected mAs.

Additional fixed-technique measurements were performed with the dosimeter centered over each AEC cell location to quantify the combined effects of the heel effect and off-axis beam geometry. A heel-effect scaling factor (HESF) was defined as:

$$\mathrm{HESF}(cell_i) = \frac{\text{Peripheral}-cell_i \text{ air kerma}}{\text{Center}-\text{cell air kerma}}$$

Additional flat-field images were acquired to characterize the relationship between MPV and detector air kerma.

Grids were removed for all measurements.

DATA ANALYSIS

Cell balance was defined as the percentage difference in response at each peripheral AEC cell relative to the center cell. It was calculated using the following measurement methodologies:

- System-reported mAs
- Heel-effect-corrected mAs
- EI
- Heel-effect-corrected EI
- MPV
- MPV converted to air kerma
- Directly measured air kerma

Measured air kerma cell balance served as the ground-truth reference. Agreement with ground truth was evaluated separately for table and wall systems. Mean paired differences, defined as method minus ground truth, and corresponding 95% confidence intervals (CIs) were calculated. Paired t-tests were used to determine whether the mean differences were significantly different from zero. P-values were adjusted for multiple comparisons within each system type using the Holm method. Statistical significance was defined as a Holm-adjusted p-value < 0.05.

Heel-effect scaling factors were summarized by median and range separately for table and wall systems along with their corresponding source-to-image distance (SID) ranges.

RESULTS

All evaluated x-ray tubes had target angles ranging from 12.5° to 13°.

Before correction, mAs, EI, and MPV demonstrated significant bias relative to measured air kerma for both table and wall systems.

For **table systems**, application of the heel-effect correction substantially reduced bias for all three metrics. Corrected mAs, EI, and MPV were no longer significantly different from ground truth.

For **wall systems**, the correction reduced the bias in mAs and EI, and neither corrected metric differed significantly from ground truth. Corrected MPV, however, remained significantly different from ground truth.

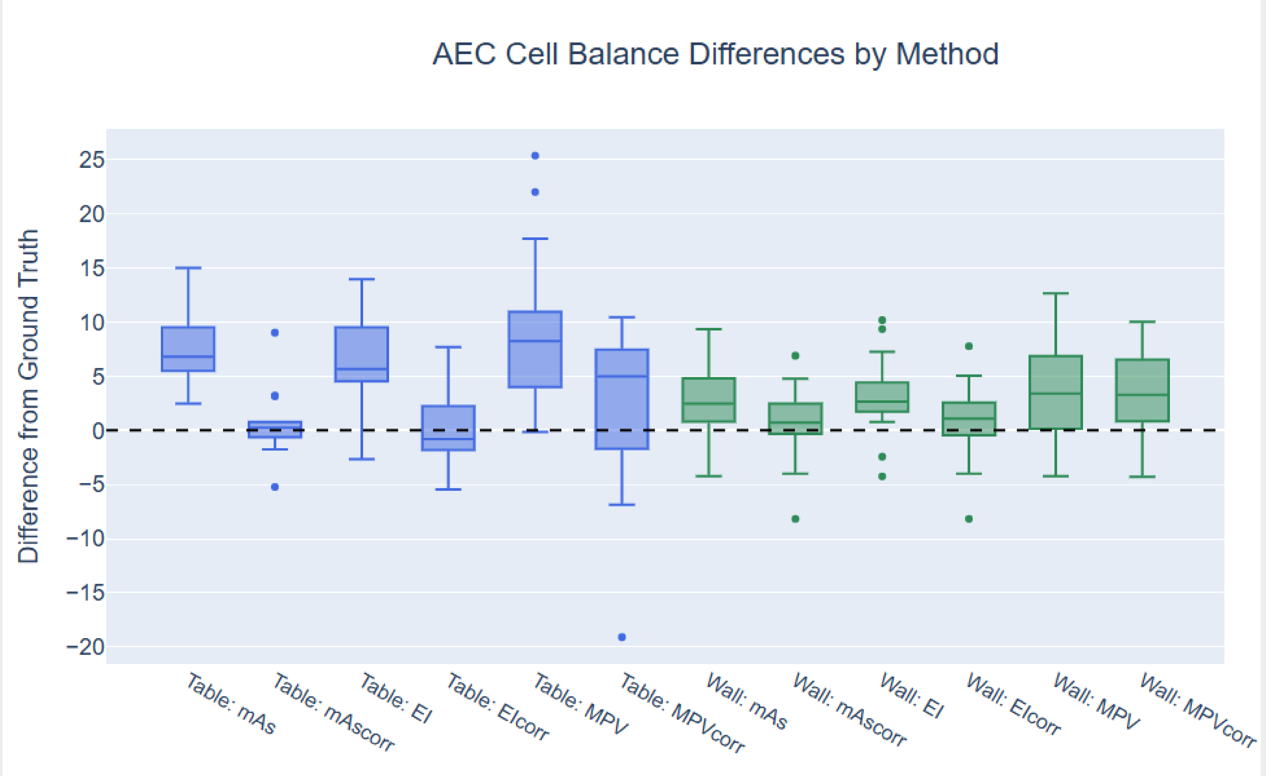

Figure 1. Differences between AEC cell balance metrics and measured air kerma cell balance for table and wall Bucky systems. The dashed line represents zero difference from ground truth. Positive values indicate overestimation relative to measured air kerma.

Method	Table: Mean Difference	Table: Corrected p-value	Wall: Mean Difference	Wall: Corrected p-value
mAs	7.55	<0.001	2.94	0.010
mAs_{corr}	0.56	1.000	0.67	0.643
EI	6.92	<0.001	3.13	0.009
EI_{corr}	−0.03	1.000	0.86	0.643
MPV	9.22	0.003	3.60	0.017
MPV_{corr}	2.10	1.000	3.52	0.009

Table 1. Paired comparisons between AEC cell balance metrics and measured air kerma. Table-system results included 14 comparisons, and wall-system results included 18 comparisons. Mean differences represent method minus ground truth. P-values were adjusted for multiple comparisons using the Holm method. Significant p-values shown in red.

Heel-effect scaling factors were lower and more variable for table systems than for wall systems:

- Table systems: median 0.93, range 0.88–0.97; SID range 100–114.6 cm
- Wall systems: median 0.98, range 0.95–1.01; SID range 178–183 cm

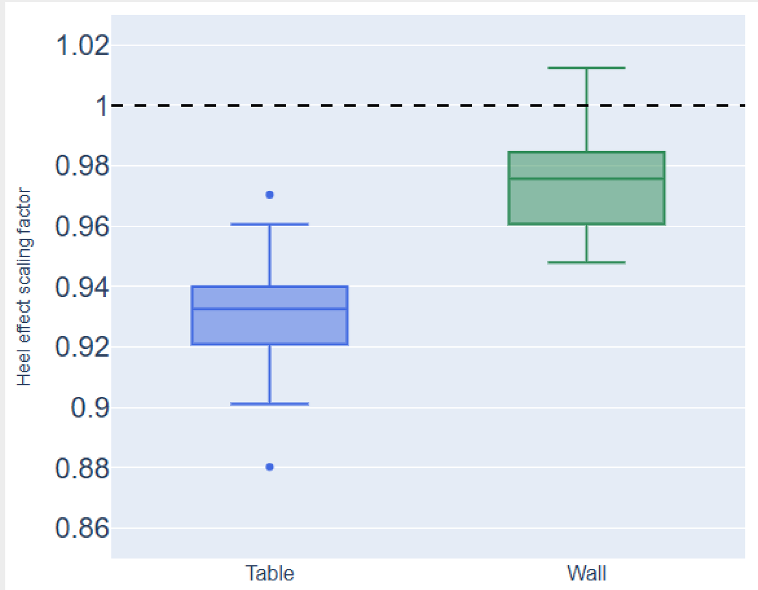

Figure 2. Heel-effect scaling factors for table and wall systems. Scaling factors were defined as the air kerma measured at a peripheral AEC cell location divided by the air kerma measured at the center-cell location using a fixed exposure technique.

DISCUSSION

The shorter SIDs used for table Bucky imaging produced stronger spatial beam-intensity gradients across the AEC cell locations. The median heel effect scaling factor was 0.93 for table systems compared with 0.98 for wall systems.

When beam non-uniformity was not accounted for, mAs, EI, and MPV overestimated cell imbalance relative to directly measured air kerma. For table systems, the mean bias exceeded 5% for all three uncorrected metrics and approached 10% for MPV. These differences are practically significant relative to the commonly recommended ±15% AEC cell balance performance limit[1]. Beam nonuniformity could therefore cause a system with acceptable AEC performance to appear close to or outside the recommended tolerance.

Applying the heel-effect correction substantially improved agreement between mAs- and EI-based measurements and ground truth. Corrected mAs and EI did not differ significantly from measured air kerma for either table or wall systems, suggesting that these corrected metrics may provide practical methods for routine AEC cell balance testing.

MPV-based results were less consistent. Although correction reduced MPV bias for table systems, corrected MPV remained significantly biased for wall systems. MPV may be affected by vendor-specific flat-field, gain, or other image corrections applied to *for-processing* images and may not provide a direct or spatially invariant measure of detector air kerma.

CONCLUSIONS

Heel-effect-induced beam nonuniformity produces systematic differences in AEC cell balance measurements, particularly for table Bucky systems operating at shorter source-to-image distances. When the heel effect is not considered, AEC cell balance testing may falsely indicate system imbalance.

Correcting mAs and EI for spatial beam-intensity differences improved agreement with measured air kerma for both table and wall systems. Heel-effect-corrected mAs and EI therefore appear to be practical metrics for AEC cell balance testing.

These findings may help medical physicists distinguish true AEC performance differences from beam nonuniformity and support future refinement of radiographic AEC quality control recommendations.